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A SYSTEMATIC REVIEW ON HEALTH BENEFITS OF FERMENTED FOODS AND BEVERAGES

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ABSTRACT

Background: Foods and beverages such as- fermented milk, cheese, yogurt, koumiss, kefir, natto, miso, fermented rice, fermented rice bran, buckwheat, legumes, vinegar, sauerkraut and sourdough, have been consumed in different regions of the world. **Objective:** To highlight the potential health benefits conferred by the consumption of fermented products. **Methods:** The primary research articles were taken from “Google Scholar”, “PubMed”, “Research Gate” and “Scopus” sites through keywords like “Fermented Foods” and “Health Benefits of Fermented Foods” from the year 2006 to 2022. A total of 33 articles were found to meet the inclusion criteria after screening through the QUORUM diagram for this study, and the risk of bias graph was plotted to control the bias. **Results:** This review highlights the health benefits conferred by different fermented foods and beverages. However, more studies may be required to derive conclusions for quantitative and qualitative information, such as nutrient composition or quantities that are required for conferring the myriad health benefits associated with the consumption of these fermented foods and beverages. **Conclusions:** This review aids researchers and nutrition policy makers in focusing on various health benefits of consuming fermented foods and beverages. It also helps researchers in identifying literature gaps to pursue their study.

Keywords: fermented foods, fermented beverages, health benefits, *Lactobacillus*

INTRODUCTION

The age-old and most economical process used in preparing food is known as fermentation, and is stated as the process of

preservation of foods involving microbial growth and metabolic activities [1-2]. There are two categories in food fermentation-

aerobic which involves fungal or alkaline activities, and anaerobic which involves the production of alcoholic or lactic acid activities. The microbial enzymes react with complex food substances in producing metabolites that affects its organoleptic and functional properties despite of the type of fermentation involved [3].

The four fermentation techniques in foods and beverages includes acetic acid, lactic acid, alkali or alcohol are produced through controlled growth of microbes and their enzymatic reactions [4-5]. Lactic acid fermentation is caused by *Lactobacillus* spp., and *Pedicoccus*, *Streptococcus* and *Leuconostoc* were found to be involved in the fermentation of meat, vegetable and dairy products. Acetic acid fermentation has been caused by Acetic acid bacteria like *Glucon acetobacter* for cocoa, kombucha and vinegar fermentation. Alcoholic fermentation is carried out by yeasts like *Saccharomyces cerevisiae* for beer, breads and wine production. Alkaline fermentation and maturation of products such as cheese, soy and meat is carried out by *Aspergillus* species or *Penicillium* species [6-7].

There are several mechanisms of fermentation of foods involving different micro-organisms, and through which the following benefits on health may be conferred:

- a) The presence of potential probiotic micro-organisms [5].

- b) The metabolites obtained through fermentation.
- c) The reduction of toxins and other anti-nutrient components such as the reduction of phytic acid concentrations in fermented soybeans or fermentable carbohydrates in fermented sourdough. This is better tolerated in people with irritable bowel syndrome and other gastrointestinal diseases [12].

During the process of fermentation, micro-organisms produce metabolites including carbon dioxide, alcohol and organic acids as the result of the breakdown of fermentable carbohydrates in that food [8]. They also ensure the inhibition of activity or killing food borne pathogens such as Bacteriocins. This increases the safety of foods through its anti-microbial activities.

Fermentation process enhances certain properties of foods as follows:

1. Organoleptic (sensory) properties
2. Increase in shelf-life of highly perishable food products
3. Digestibility of carbohydrates and proteins
4. An increase in the bioavailability of minerals and vitamins in those foods.

Fermented foods were also found to possess bioactive peptides like-Valyl-Prolyl-Proline (VPP), Isoleucine-Proline-Proline (IPP) and Phenylalanine-Proline (FP), which were found to exert an effect on various

physiological parts of the body including digestive, cardiovascular, immune system, endocrine and nervous system [10]. These bioactive peptides were synthesized during microbial breakdown of proteins by bacteria or due to endogenous proteolytic enzymes during fermentation and the ripening process [9-11].

Consumption of foods that are fermented provides positive health effects by protecting against pathogens, controlling cholesterol levels in the blood, preventing obesity, shielding against carcinogens, diabetes, allergies, atherosclerosis, osteoporosis, lactose intolerance symptoms, and conferring better immunity [5]. In many developing countries, fermented foods and beverages have existed since ancient times as part of tradition and local cultures, and is an indispensable part of the daily diet [8]. Fermented products are considered ubiquitous in the diet due to its health-promoting, sensory and nutritious qualities. However, well-established and precise associations among health and consumption of fermented products are not widely available [16]. Another factor which paved the way for this study was the growing interest on the consumption of these foods and beverages in India and other countries [5]. These fermented products are considered to be rich in many nutrients like proteins, essential amino acids, essential fatty acids, vitamins, minerals, and soluble fiber. Their probiotic

content due to the presence of certain microbial strains like LAB (Lactic Acid Bacteria) had conferred functional benefits in balancing the intestinal microbiota and having a positive impact on treatment of certain diseases.

Therefore, this review is essential to understand common fermented foods and beverages, required composition and related health benefits of these products on human population. Thus, this systematic review was undertaken to understand the potential health benefits of live micro-organisms found through the consumption of foods and beverages that have been fermented, and also assesses the role of these foods in various clinical and epidemiological studies previously conducted. With this focus, the following objectives were framed and studies pertaining to these were reviewed:

1. Commonly available fermented foods and beverages in India and other countries.
2. Studies pertaining to health benefits of fermented foods and beverages.

METHODOLOGY

The primary research articles were taken from “Google Scholar”, “PubMed”, “Research Gate” and “Scopus” sites with keywords such as “Fermented Foods” and “Health Benefits of Fermented Foods” from the year 2006 to 2022. QUORUM diagram (Figure 1) was structured to arrive at the right number of articles for this systematic review. A total of 33 articles were found to meet the inclusion criteria of this study.

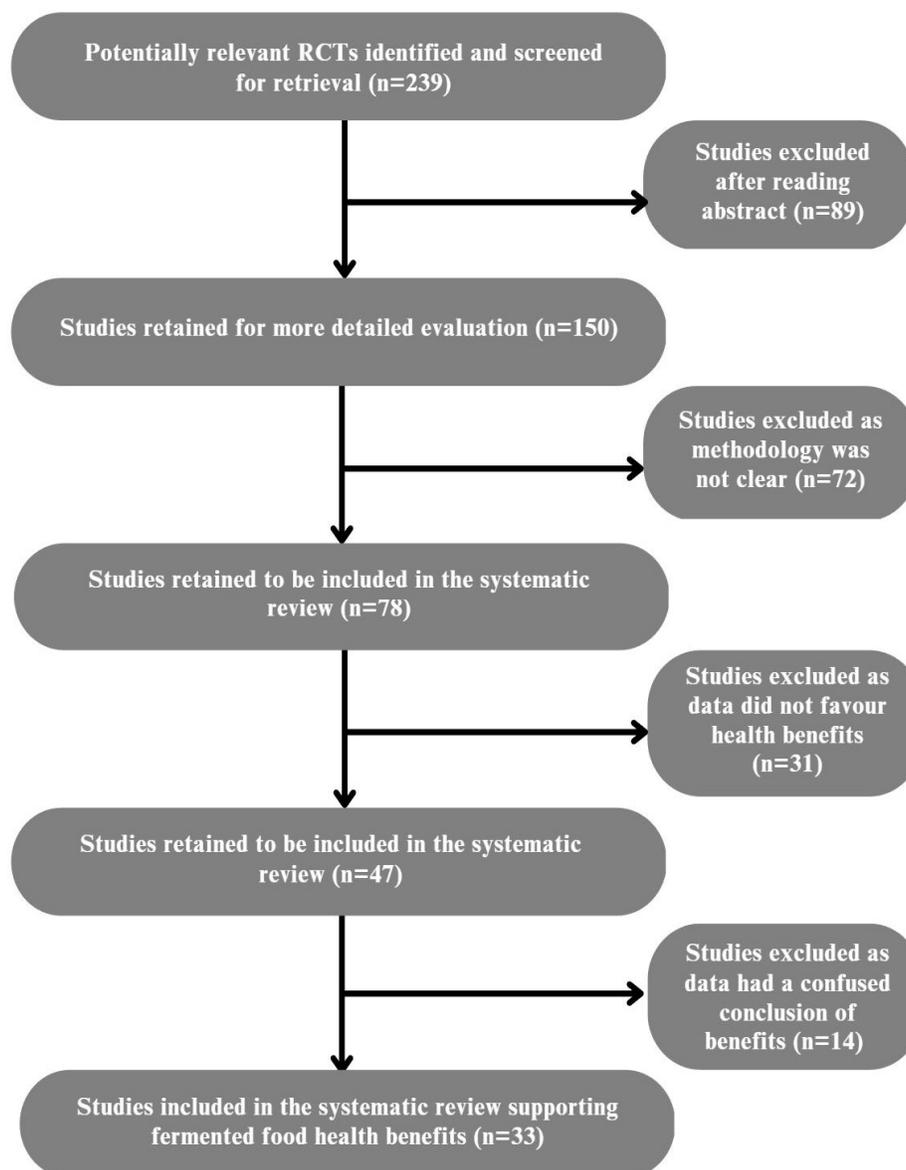


Figure 1: QUORUM Chart for Systematic Review

Inclusion Criteria

1. Original research articles found to be published from 2006 to 2022 were taken in this study.
2. Articles that covered health benefits of fermented foods from all over the world were included.

Exclusion Criteria

1. Studies based on systematic and/or meta-analysis were excluded.
2. Studies published in languages apart from English were excluded.

The Cochrane's Risk of Bias Graph was used to depict the risk of bias amongst the 33 RCTs which were selected for this review. The graph is provided in **(Figure 2)**.

	1	2	3	4	5	6	7
Andrade and Borges, 2009	?	?	+	+	?	?	?
Usinger et al., 2010	+	+	+	?	?	?	?
Jauhiainen et al., 2012	+	+	+	?	?	?	?
Rodriguez-Figueroa et al., 2013	+	+	?	?	?	+	?
Chen et al., 2014	?	?	+	+	+	+	?
Sofi et al., 2010	?	+	-	-	+	+	?
Pouliot-Mathieuet al., 2013	?	?	-	-	+	?	?
Pashapour and Iou, 2006	+	+	+	+	?	?	?
Bekar et al., 2011	+	+	+	+	+	+	?
Turan et al., 2014	+	+	+	+	?	?	?
Ostadrachimiet al., 2015	+	+	+	+	+	+	?
Fathi et al., 2017	+	+	-	-	?	?	?
Yilmaz et al., 2017	?	+	-	-	?	?	?
Mitsui et al., 2006	?	+	-	-	?	?	?
Ikeda et al., 2006	?	+	-	-	?	?	?
Park et al., 2012	+	+	+	+	?	?	?
Yoshinaga et al., 2012	+	+	+	+	?	?	?
Bhaskar et al., 2021	+	+	+	+	?	?	?
Choi et al., 2014	+	+	+	+	?	?	?
Shibata et al., 2006	+	+	+	+	+	+	?
Nakamura, Naramoto and Koyama, 2012	+	+	+	+	+	+	?
Kwon et al., 2007	+	+	+	+	+	+	?
Choi et al., 2016	+	+	+	+	+	+	?
Yeap et al., 2012	+	+	+	+	+	+	?
Ademiluyi and Oboh, 2012	+	+	+	+	+	+	?
Johnston et al., 2010	+	+	-	-	?	?	?
Lee et al., 2013	+	+	+	+	+	+	?
Chou et al., 2015	+	+	+	+	+	+	?
Nielson et al., 2018	+	+	+	+	+	+	?
Korem et al., 2017	+	+	-	-	?	?	?
Laatikainen et al., 2017	?	+	-	-	?	?	?
Raninen et al., 2017	+	+	+	+	+	+	?
Polese et al., 2018	+	+	+	+	+	+	?

Low risk of Bias
 Unclear risk of Bias
 High risk of Bias

1- Random Sequence Generation (selection bias), 2- Allocation Concealment (selection bias), 3- Blinding of Participants and Personnel (performance bias), 4- Blinding of Outcome Assessment (detection bias), 5- Incomplete Outcome Data (attrition bias), 6- Selective Reporting (reporting bias), 7- Other Bias.

Figure 2: Assessment of Risk of Bias for the selected studies using Cochrane’s Risk of Bias for RCTs

RESULTS



Figure 3: Depiction of the origin of the most common Fermented Foods and Beverages throughout the World (Modified from: <https://www.howtocook.recipes/36-fermented-foods-from-around-the-world/?amp>)

Table 1: Fermented Foods and their Health Benefits – A Review of studies.

Fermented Food	Type of Study	Details of Sample	Consumption specifications	Health Benefits reported	References
Fermented Milk (FM) with <i>L. acidophilus</i> 145 and <i>B. longum</i> BB536	Placebo controlled, Double-blind, crossover trial	34 women aged 18 and 65 years	Group A-125g FM, 3 times/d- 4 weeks Group B-125g Yogurt, 3 times/d-4 weeks. Washout period-1 week, intervention swapped between groups for another 4 weeks with same specifications.	Reduction in the levels of LDL cholesterol was observed in Group A.	Andrade and Borges, [18]
Fermented Milk with <i>L. helveticus</i>	Randomized Double-blind, Placebo controlled trial	94-borderline hypertensive people	Cardi04-300 ml (Group 1), Cardi04-150 ml (Group 2), Placebo (Group 3) for 8 weeks	Sympathetic activity was reduced. No change in the ACE-inhibition activity.	Usinger <i>et al.</i> , [19]
Fermented Milk (FM) with <i>L. helveticus</i> LBK-16H	Double-blind Randomized, parallel, Placebo controlled study	89-mildly hypertensive people	FM with 5mg/d lactotriptides- 3 months followed by FM with 50mg/d lactotriptides (or) Placebo (milk without lactotriptides were given for next 3 months. Total intervention-6 months.	A significant decrease in Diastolic and Systolic Blood Pressure with an intake of 50 mg lactotriptide.	Jauhainen <i>et al.</i> , [20]
Fermented Milk with <i>L. lactis</i>	Randomized, controlled, Rat study	Spontaneous hypertensive male rats (271 (SD14) g)	Group 1- FM with <i>L. lactis</i> NRRL B-50 571 at 35mg protein/kg BW, Group 2-FM with <i>L. lactis</i> NRRL B-50 572 at 50mg protein/kg BW, Group 3- saline solution, Group 4- Captopril 40mg/kg BW and BP was measured after 2,4,6 and 24 hours of consumption.	There was a significant reduction in the heart rate due to the reduction of systolic and diastolic blood pressure.	Rodriguez-Figueroa <i>et al.</i> , [21]
Fermented Milk with H9 <i>L. helveticus</i>	Rat Study	Spontaneous hypertensive rats	Group 1-H9 FM- 7 weeks, Group 2, Saline, Group 3-Commercial yogurt, Group 4-Captopril.	A significant decrease after 6- and 12-hours check was noticed in Group 1 hypertensive rats.	Yongfu Chen <i>et al.</i> , [51]
Cheese naturally rich in CLA	Dietary Intervention Crossover study	10 participants (6 F, 4 M) age between 45-55 years	200g/week CLA enriched cheese -experimental group 200g/week commercial cheese - control group 10 weeks	A reduction in Platelet aggregation and anti-inflammatory parameters like IL-8, IL-6 and TNF- α were reported.	Sofi <i>et al.</i> , [23]
Cheddar Cheese naturally enriched with GABA producing <i>L. lactis</i>	Placebo, controlled study	23 men aged 23 to 63 years	Experimental Group-50g/d cheddar cheese (containing 16mg of GABA), Control Group- placebo cheese 12 weeks	A significant reduction was observed in mean and systolic blood pressure.	Pouliot-Mathieu <i>et al.</i> , [24]
Pasteurized cow milk Yogurt	Randomized, controlled	80-moderately dehydrated, breastfeeding children between 6-24 months with acute non-bloody and non-mucoid diarrhea >4 days	Case Group-15 ml/kg/day pasteurized cow milk yogurt + routine hospital treatment, Control Group- Routine hospital treatment.	A significant reduction in hospital stays and diarrhea, and an increase in weight gain was observed in the case group.	Pashapour and Iou, [25]

Kefir	double-blind, randomized controlled Study	82 patients with dyspepsia symptoms and <i>H. pylori</i> infection confirmed with Urea Breath Test	Intervention group: Triple therapy (lansoprazole (30 mg), amoxicillin (1,000 mg), and clarithromycin (500 mg) + kefir- 250 ml twice/d Control group: Triple therapy + milk- 250 ml twice/d 2 weeks	<i>H. pylori</i> eradication rate was higher, and abdominal pain, diarrhea and headache were considerably reduced.	Bekar <i>et al.</i> , [26]
Kefir	Non-randomized, uncontrolled, intervention Study	20 patients with functional constipation as per Rome II criteria	Kefir- 500 ml/d for 4 weeks.	Stool frequency was increased and bowel satisfactory scores were improved.	Turan <i>et al.</i> , [27]
Kefir	Double-blind, placebo controlled, randomized, clinical trial	60 diabetic patients aged 35 to 65 years	Experimental Group-600ml/d kefir Control group- 600ml/d conventional milk 8 weeks	It reduced serum glucose, baseline HbA1c levels and energy intake.	Ostadrhimi <i>et al.</i> , [28]
Kefir	Single-center, multi-arm, parallel group, outpatient, Randomized, controlled trial	75 Iranian women aged 25 to 45 years overweight/obese premenopausal women	Experiment group: 2 servings of kefir + 2 servings-skimmed milk/d. Control group: 2 servings-skimmed milk/d.	Plasma lipoprotein levels were considerably reduced in experimental group.	Fathi <i>et al.</i> , [29]
Kefir	Single-center, prospective, open-label RCT	45 patients with IBD	400ml/d kefir for 4 weeks day and night.	Blood hemoglobin had higher change in Crohn's disease patients who consumed kefir.	Yilmaz <i>et al.</i> , [30]
Natto	Controlled trial	50 patients with IBD	Intervention group: natto with <i>Bacillus subtilis</i> 50g/d Control group: boiled soybeans- 50g/d. 2 weeks	Stool quantity was increased and higher number of days with frequent bowel movements were reported.	Mitsui <i>et al.</i> , [31]
Natto	Japanese-Population based Osteoporosis Study	944 women between 20 to 79 years age.	Group 1-natto- 4 weeks, Group 2-tofu-4 weeks.	Prevention of bone loss in postmenopausal women were prevented by natto, which was found to possess isoflavone or menaquinone 7 effect.	Ikeda <i>et al.</i> , [32]
Natto	Rat Study	50 - 4 to 6 weeks old Sprague-Dawley male rats	G1- normal rats-vehicle only, G2-hypercholesterolemic rats-vehicle only, G3-hypercholesterolemic rats-750mg natto powder/head/d-4 weeks, G4-hypercholesterolemic rats-1500mg natto powder/head/d-4 weeks, G5-hypercholesterolemic rats-aspirin 100mg/kg/d-4 weeks	In hypocholesterolemic rats an inhibitory effect on fibrinolytic activity and platelet aggregation induced by adenosine 5' diphosphate was noted in normal natto consumption groups.	Park <i>et al.</i> , [33]
Miso	Rat Study	20 Dhal-salt sensitive rats	G1-water, G2-0.9% NaCl solution, G3-1.3% NaCl solution, G4-miso soup containing 1.3% NaCl 8 weeks	Consumption of miso soup has recorded benefits of decreased blood pressure which was considered to be similar in effect after consumption of hypertensive drugs.	Yoshinaga <i>et al.</i> , [34]
Fermented Rice Extract (FRE)	Rat Study	15 normal rats	FRE in 3 doses of 100, 200, 300mg/kg/d -15 days.	Fermented rice extract had a laxative effect on the rats without causing diarrhea and can be prescribed as complementary medicine for humans with constipation.	Choi <i>et al.</i> , [35]
Fermented Brown Rice (FBRA)	Rat Study	20 Long-Evans Cinnamon rats	G1- 5% FBRA, G2-10% FBRA 12 weeks	After consumption of FBRA by hepatitis rats, a protective effect was reported and	Shibata <i>et al.</i> , [36]

				minute changes were noted between the two groups.	
Fermented Buckwheat with LAB	In-vitro Study	20 Spontaneous hypertensive rats	G1-0.01mg/kg fermented buckwheat with LAB, G2-1mg/kg captopril.	Blood pressure lowering effects were observed when fermented buckwheat was consumed along with LAB.	Nakamura, Naramoto and Koyama, [37]
Fermented Soybeans with <i>B. subtilis</i>	In-vitro Study	10 Px rats	G1-14g/d cooked unfermented soybeans (CSB), G2-14g/d fermented unsalted soybeans with <i>B. subtilis</i> (CKJ) 8 weeks	Insulinotropic action was induced by small peptides production in the pancreatic beta cells among type 2 diabetic rats in G2	Kwon <i>et al.</i> , [38]
Fermented Soybeans with <i>B. licheniformis</i> -67	Rat Study	40 male mice C57BL/6J aged 4 weeks	G1-normal diet, G2-high-fat diet, G3-high-fat diet + 30% unfermented soybean, G4-high-fat diet + 30% fermented soybean with <i>B. licheniformis</i> -67 13 weeks	May alleviate fatty liver disease and insulin resistance that are obesity related and also exhibited a beneficial effect on metabolic syndrome through an effect on its associated biomarkers among rats that consumed fermented soybeans with <i>B. licheniformis</i> -67.	Choi <i>et al.</i> , [39]
Fermented Mung Bean (FMB)	Rat Study	5 normal mice, 5 alloxan induced-hyperglycemic mice	G1-normal mice- FMB, G2-alloxan induced-hyperglycemic mice-FMB 4 weeks	Certain measured antioxidant levels among G1 were significantly increased, and LDL-cholesterol, plasma fasting glucose, triglycerides and cholesterol were significantly reduced.	Yeap <i>et al.</i> , [40]
Fermented Legumes	Rat Study	36 adult male Wister diabetic rats	G1-fermented Bambara groundnut, G2-Locust bean, G3-Soybean diet 14 days	In diabetic rats, a modulating effect on oxidative stress and liver tissue damage due to increased contents of phenolic antioxidants when fermented legumes-based diet was consumed.	Ademiluyi and Oboh, [41]
Vinegar	Randomized, crossover Study	40 adults with or without diabetes	G1-10 g vinegar, G2-20g vinegar, G3-Bagel and juice meal, G4-dextrose solution-measured 120 minutes after meal.	23% decrease in postprandial glycemia was observed in G1 and G2 when compared with other 2 groups.	Johnston <i>et al.</i> , [42]
Tomato Vinegar	Rat Study	10 adult male rats	Experimental group: tomato vinegar, control group: high-fat diet without vinegar.	A significant reduction in visceral fat accumulation and lipids in adipocytes and a reduction in LDL-cholesterol in plasma was reported.	Lee <i>et al.</i> , [43]
Vinegar	In-vivo Study	20 Hamsters	G1-high-fat/cholesterol diet (HFCD) + Black vinegar, G2-low-fat/cholesterol diet (LFCD) 8 weeks	Cholesterol lowering and antioxidant effects were exhibited in HFCD group hamsters due to black vinegar intake.	Chou <i>et al.</i> , [44]
Lacto-fermented Sauerkraut	Randomized, controlled double-blind study	34 Norwegian IBS patients	Intervention group: unpasteurized sauerkraut- 75g/d containing LAB, Control group: pasteurized sauerkraut- 75g/d 6 weeks	Low score on IBS-SSS for both pasteurized and unpasteurized sauerkraut and no significant difference between the groups were identified.	Nielson <i>et al.</i> , [50]
Sourdough whole wheat bread	Randomized, crossover study	20 healthy male and female subjects	Intervention group: sourdough whole wheat bread- 145g/d, Control group: white wheat bread- 110g/d 7 days.	Glycemic responses were having a significant variation in the intervention group.	Korem <i>et al.</i> , [46]

Wheat sourdough bread	RCT, Double blind study	26 subjects with IBS	Intervention group: wheat sourdough bread (fermented for more than 12 hours)- 6 slices/d, Control group: wheat bread fermented for approx. 2 hours with yeast – 6 slices/d 1 week.	There was no significant difference in the markers of low-grade inflammation and GI symptoms between the 2 groups.	Laatikainen <i>et al.</i> , [12]
Sourdough wholegrain rye bread	Randomized, controlled, crossover, double-blind study	7 subjects both male and female	Intervention group: sourdough wholegrain rye bread- 6-10 slices/d Control group: wheat bread enriched with fermented rye bran- 6-10 slices/d. 4 weeks	In fasting state, a significant difference was found in intervention group in exhaled breath volatile organic compound profile.	Raninen <i>et al.</i> , [47]
Sourdough croissants	Randomized, controlled, crossover, double-blind study	17 healthy adults (9 F, 8 M) aged 18 to 40 years.	Intervention group- sourdough croissants- 2/d. Control group- brewer's yeast croissants- 2/d.	Gastric volume was reduced by 11% post consumption and hydrogen production was reduced 30% for 4 hours after consumption of sourdough croissants.	Polese <i>et al.</i> , [48]

Abbreviations: B., Bifidobacterium; L., Lactobacillus; ACE, Angiotensin Converting Enzyme; BW, Body Weight; BP, Blood Pressure; CLA, Conjugated Linolenic Acid; F, Females; M, Males; IL, Interleukin; TNF, Tumor Necrosis Factor; GABA, Gamma-Amino Butyric Acid; H., Helicobacter; IBD, Irritable Bowel Disease; G, Group; LAB, Lactic Acid Bacteria; CSB, Cooked Soybeans; CKJ, Chungkookjang (fermented soybeans); IBS-SSS, Irritable Bowel Syndrome Severity Scoring System; GI, Gastrointestinal; RCT, Randomized Controlled Trial

DISCUSSION

In India, the tradition of fermentation of foods and beverages has largely been due to ancestral influence on households. However, in western countries, technological and scientific revolutions had changed the household processes into industrial productions, suitable for a larger population and intended for marketplaces. Using various food matrices, different manufacturing techniques and micro-organisms, a varied range of foods and beverages are being fermented globally [17], this is depicted on the world map (Figure 3).

At present, fermentation is being carried out in more than 5000 varieties of foods and beverages in the world, and its accelerated growth in the markets is due to the increasing trends on healthy food consumption and conscious eating pattern. Various foods and beverages are being fermented and consumed by people native to a particular region such as products of dairy (yogurt, cheese, buttermilk) in Europe, soy (soy sauce, natto, doubanjiang, miso) in East Asia, cereals and pulses (injera, dosa, idli, dhokla, pazhayadhu) in Africa and South Asia [4, 13-14]. Few other products are less culturally or regionally dependent and they possess different regional names in each of these regions which includes fermentation of fish consumed in Norway (rakfisk), Japan

(narezushi), Korea (sikhae) and Sweden (surstromming) [4, 15].

The metabolites from the micro-organisms along with the enzymatic activities happening in the food matrices are being understood to improve the nutritive components and bioactive food properties, resulting in molecule production leading to health-promoting activities [5]. The development of health-promoting factors in the food substances (i.e., cereals, meat, fish, milk, fruits and vegetables) after fermentation are depicted and analysed with major emphasis on the type of fermented food ingested, consumption specification and health benefits conferred [17] (Table 1).

CONCLUSION

From the review on studies conducted for the past 15 years, it is observed that foods and beverages have been fermented and traditionally consumed throughout the world, and majority of the health benefits conferred were in relation to Gastrointestinal disorders/disease, Cardiovascular diseases, Hypertension and management of body weight. Though most of the studies were animal and in-vitro studies, further elaboration of these clinical trials would be required to associate these health benefits with human population on a larger scale. The fermentation of foods has also been shown to increase the nutrient content when compared with its non-fermented counterparts. The composition of

each fermented food and beverage in which these health benefits would be obtained are also to be further scrutinized for extensive usage of these super foods. Areas related to Reproductive health and allied conditions could also be taken into account in future research studies.

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